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RESEARCH DEPARTMENT

Some applications of birefringent polarizing prisms in flying-spot scanning

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SOME APPLICATIONS OF BIREFRINGENT POLARIZING PRISMS IN FLYING-SPOT SCANNING

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(1965/52)

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for Head of Research Department

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SOME APPLICATIONS OF BIREFRINGENT POLARIZING PRISMS IN FLYING-SPOT SCANNING

SUMMARY

The properties of Wollaston birefringent polarizing prisms are examined. The device is shown to be useful as a means of obtaining twin scanning-spots in a flying-spot film scanner. Outline suggestions are given for the possible application of twin-spot scanning, in the simulation of standards conversion and vertical aperture correction in pictures.

1. INTRODUCTION

Since their discovery by Bartholinus in 1669, the birefringent properties of optically-transparent crystalline materials have been utilized in numerous optical instruments and devices, usually associated with the production and measurement of polarized light. The behaviour of rays of light in plates and prisms cut from crystalline materials is well described in text books on Physical Optics, where the now classical polarizing prisms devised by Nicol, Wollaston, Rochon and others are usually cited. The basic function of these polarizing prisms is to produce, from an incident ray of light, two rays which emerge travelling in different directions (or laterally displaced) and distinguishable from each other by the fact that they are polarized at right angles to one another. For the applications to be proposed later, we are interested in making use of both these effects (i.e. angular separation and orthogonal polarization). The prisms of immediate interest, therefore, would be of the Rochon or Wollaston types.

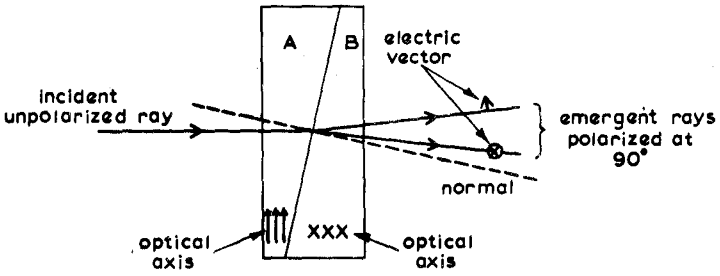
2. THE WOLLASTON PRISM

2.1. General Description

The Wollaston prism is constructed by combining two prisms, cut from a uni-axial crystal, so that the optical axes of the prisms are at right angles and, in addition, are parallel to the outer faces of the prism. This is shown in Fig. 1 which represents a plane section orthogonal to both the inner and outer faces of the prism. Thus, in the component prism A the optical axis (which, it should be remembered, is not a single axis but, rather, a direction) lies parallel to the plane of the paper, but in the second component prism B it is normal to the paper.

Fig. 1

The Wollaston prism



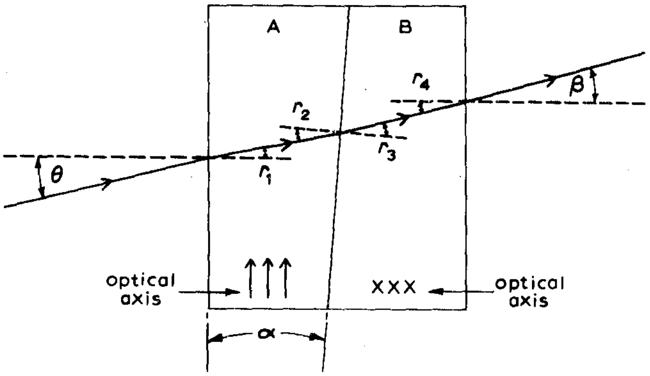
If the prism is cut from crystalline quartz, which is a positive uni-axial crystal, the velocity of propagation of light in the crystal is slightly faster for waves having an electric vector at right angles to the optical axis of the quartz (the ordinary ray or 'O' ray) than it is for waves wherein the electric vector is parallel to the optical axis (the extraordinary ray or 'E' ray). Thus, referring again to Fig. 1, the basic action of the prism is seen by considering an incident ray of unpolarized light which strikes the outer face of the component prism A normally. In the first prism the O and E waves travel in the same direction but with different velocities. In the second prism the O wave becomes the E wave and thus propagates with the E-wave velocity, while the original E wave becomes the O wave and travels at the O-wave velocity. Thus at the contact interface of the prisms the ray directions diverge, one component being refracted away from the common normal to the contact interface and the other refracted towards this normal. If the emerging rays are viewed through a piece of Polaroid (or a Nicol prism) the rays can be extinguished in turn by rotating the Polaroid.

2.2. Angular Separation

To determine the magnitude of the angular separation in a quartz Wollaston prism consider the ray diagram shown in Fig. 2. In this figure the path travelled by one of the components of a ray is shown lying in the plane of the paper but incident at an angle θ to the normal to the external surface of A. Let n_e and n_o be the principal indices of refraction of the quartz (inversely proportional to the propagation velocity) and let α be the angle between the inner and outer faces of the component prisms A and B. The internal angles r_1, r_2, r_3 and r_4 which the ray makes with the appropriate normal at the interfaces where refraction occurs are indicated on the figure. Let the angle of emergence be β.

Fig. 2

Ray path through a Wollaston prism



For one component, say the E component in the first prism A, we have the following relationships

$$\left.\begin{aligned} \sin\theta &\simeq n_e \sin r_1 \\ n_e \sin r_2 &\simeq n_o \sin r_3 \\ n_o \sin r_4 &= \sin\beta \end{aligned}\right\} \tag{1}$$

A corresponding set of equations is obtained for the other component. Also, by inspection of the prism geometry, we obtain

$$\left.\begin{aligned} & r_2 = r_1 + \alpha \\ \text{and}\quad & r_3 = r_4 + \alpha \end{aligned}\right\} \tag{2}$$

The approximation sign is necessary in equations (1) because the actual index of refraction appropriate to the propagation of an E component is only that of the principal index n_e for rays travelling exactly normal to the optical axis. Since, however, we will be concerned later with reasonably small angles of incidence ($|\theta| < 10°$, say) and small prism angles ($\alpha < 4°$, say) the error in the calculated angle of emergence β will be negligibly small if the principal index n_e is used in the equations. For the same reason (i.e. small angles of incidence) we can, with little ensuing error, replace the sines of the angles by their radian measure. It is then easy to show that

$$\beta \simeq \theta \pm (n_e - n_o)\alpha \tag{3}$$

where the positive sign or negative sign depends on which component is considered. From equation (3) it is clear that the angular separation of the two emerging rays is

$$\beta_e - \beta_o \simeq 2(n_e - n_o)\alpha \tag{4}$$

2.3. Further Considerations

In Fig. 3 is shown the variation of the difference between the principal refractive indices of quartz, $(n_e - n_o)$, with the wavelength of the light. It will

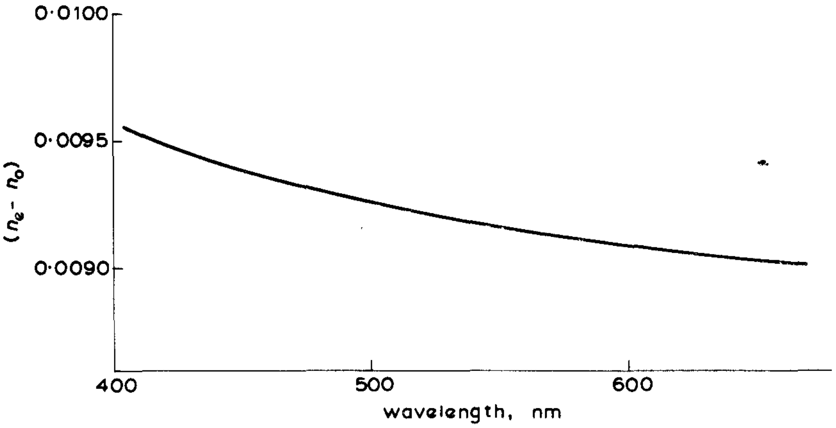


Fig. 3 - Variation of the difference between the principal indices of quartz with wavelength

be seen that the variation of $(n_e - n_o)$ over the whole visible spectrum is only of the order 6%. For many applications where only a portion of the visible spectrum is used the variation will be negligible. Thus, to a first order of approximation, equation (4) shows that the angular separation of the emergent beams is independent of wavelength - a desirable property of a Wollaston prism when it is used in lens systems concerned with maintaining good image quality over the visible band of wavelengths.

Secondly, we note from equation (4) that the angular separation is independent of the angle of incidence for small angles of incidence. Thus, providing the angular field of the optical system incorporating the Wollaston prism is not too large, the splitting properties of the prism will be substantially constant over the field. The latter conclusion is borne out by the results of measurements on a 1° Wollaston prism shown in Fig. 4. An enlarging lens was arranged to give an aerial image of a single narrow-slit test object illuminated with unpolarized white light. The lateral intensity distribution of the image (plane of best axial focus) was recorded first with the principal section of the prism parallel to the object slit (the dotted line profile in Fig. 4) and then with the prism rotated through 90° (giving rise to the double-image profiles shown by the full-lines in Fig. 4). Fig. 4(*a*) shows the results obtained when the slit-object was located on the lens axis and Fig. 4(*b*), when the object was displaced to a field position corresponding to a field angle of eleven degrees. It will be noted on comparing Fig. 4(*a*) with Fig. 4(*b*) that the separation of the double images has not altered. The image is more blurred for the 11° field position due to the lens aberration. There appears to be little, if any, deterioration in image quality between the single image and either component of the double image.

3. SOME APPLICATIONS

3.1. Intermittent-motion Flying-spot Film Scanners

In the conventional intermittent-motion film scanner each frame of the film, while stationary in the gate, is scanned by two successive fields in interlaced relationship - the odd and even scans. The output is obtained from a single photomultiplier tube receiving the light from the scanning spot after transmission through the film. However, as proposed by A.V. Lord in 1957,[1] the required output can be obtained by arranging that the odd and even field scans are carried out simultaneously, the signal corresponding to one of the scans being subsequently delayed by one field period. Briefly, Lord's arrangement suggested that the rasters on each of two flying-spot scanning tubes be optically combined so that, when imaged on the film, the spot from one scanning tube is tracing out an even field, say, while the spot from the other scanning tube is simultaneously tracing-out an odd field. In order to derive signal outputs corresponding to the picture information contained in the light from each of the two spots transmitted by the film, it is necessary to modify the quality of the light emitted by each of the scanning tubes to distinguish between them. This may be done by either polarizing the light emitted by each of the scanning tubes in mutually perpendicular planes, or by filtering the light so that different portions of the emission spectrum are used for each tube. After passage through the film two optical paths are provided each terminating in a photomultiplier tube. These optical paths are made selective by using appropriate optical filters, each being sensitive only to the light originating from one or other of the two scanning tubes respectively.

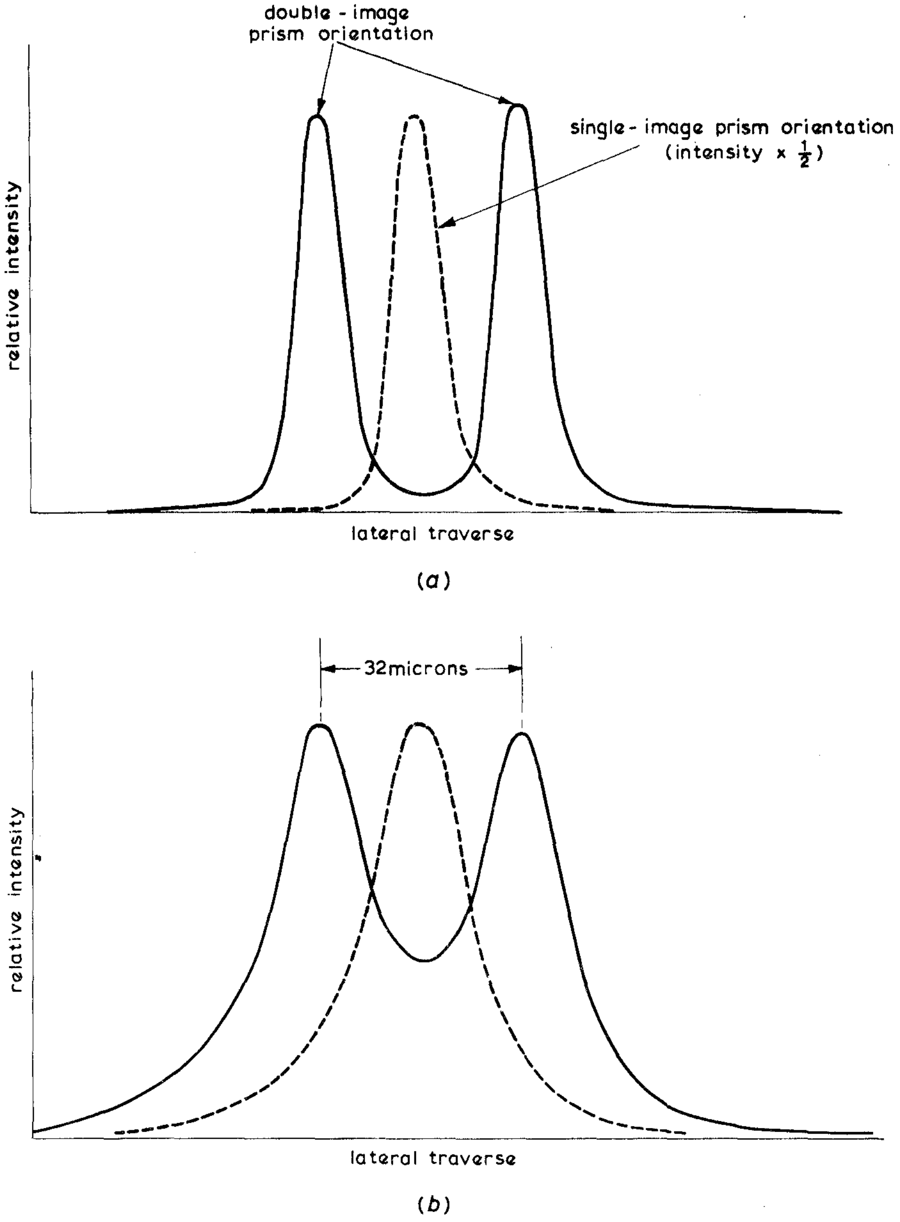


Fig. 4 - Line-image intensity profiles obtained with a lens-plus-Wollaston prism combination:

(*a*) On-axis images (*b*) 11° off-axis images

The output signal from one of the photomultipliers is passed through a delay unit which introduces a time delay equal to that of one field scan. The final output is obtained by switching from one tube output to the other at field-scan rate.

The advantage of such an arrangement is that the period available for mechanically 'pulling-down' the film in order to register the next film frame in the film gate is increased to one field period (i.e. 20 ms for 50 field interlaced standards). During the field period in which the film is being 'pulled-down' to register the next frame, the scanning tubes are both blanked-off by appropriate blanking pulses at their inputs. It may be shown that by suitable modification a similar advantage (i.e. one field period available for 'pull-down') can be obtained, also, when operating the scanner on the American 60 field interlaced standard.

It has been suggested* that the above-mentioned twin-spot scanning system might be achieved by using a single scanning tube in conjunction with a birefringent plate to give a double image of the scanning spot on the film. This is an attractive alternative method because the twin spots would be automatically polarized in mutually perpendicular planes, and the registration problem inherent in the original two-tube system would be substantially eliminated. This suggestion prompted an investigation of the optical properties of the Wollaston polarizing prism and its application as the birefringent element in such a system. One possible scanner arrangement is shown in Fig. 5. A conventional flying-spot scanning tube displays a normal interlaced raster. A Wollaston prism is placed either immediately in front of or behind the imaging lens (preferably in the long conjugate) and oriented so that a double image of the scanning spot is formed on the film, the direction of displacement being parallel to the vertical axis of the picture. The angle of the prism is such that at the required magnification of the system the twin-spot separation is exactly equal to half the distance between successive scanning lines (i.e. lines of a field). The condensing lens behind the film images the exit pupil of the imaging lens on to the photocathodes of two photomultiplier tubes. Interposed in this path is a thin-film polarizing beam-splitter, which may be, for example, one or more dielectric-coated glass plates set at the Brewster angle. The photomultiplier outputs are connected to an electronic change-over switch; a delay unit having a delay of one field period plus or minus one half-line period is inserted in the connection between one of the photomultipliers and the switch. The switch is operated by a square-wave at picture frequency and suitably phased with respect to the 'pull-down' period.

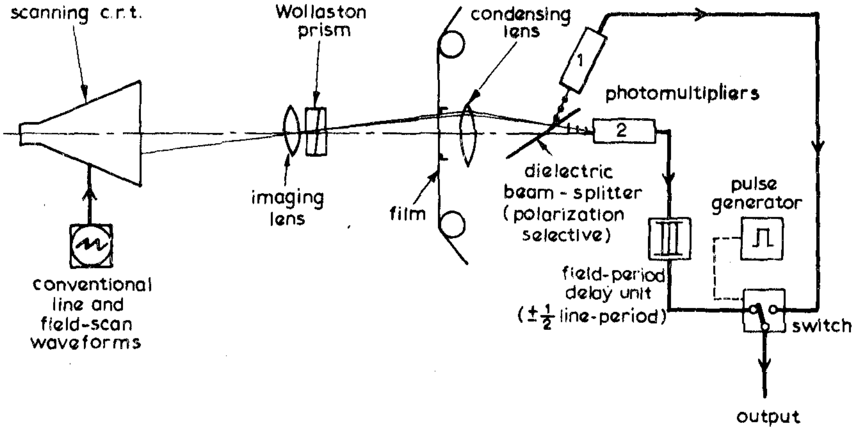

scanning c.r.t.
Wollaston prism
condensing lens
1
photomultipliers
2
dielectric beam-splitter (polarization selective)
pulse generator
imaging lens
film
conventional line and field-scan waveforms
field-period delay unit (±½ line-period)
switch
output

Fig. 5 - Application of a Wollaston prism to the intermittent-motion scanner arrangement proposed by A.V. Lord

3.2. Vertical Aperture Correction

The fact that the odd and even field picture information is available simultaneously by means of twin-spot scanning means that an ideal opportunity occurs to provide efficient vertical aperture correction in scanners. The method is basically equivalent to that originally proposed by Gibson and Schroeder[2] using delays of one field period minus one half-line period and one line period respectively, but the need to provide a delay of one field period minus one half-line period is eliminated. Thus only a line period delay is required. Hitherto vertical aperture correctors using only one or two line-period delays, but no delay of the order of a field period, have been able to use only adjacent lines of one field, rather than adjacent lines of a picture.

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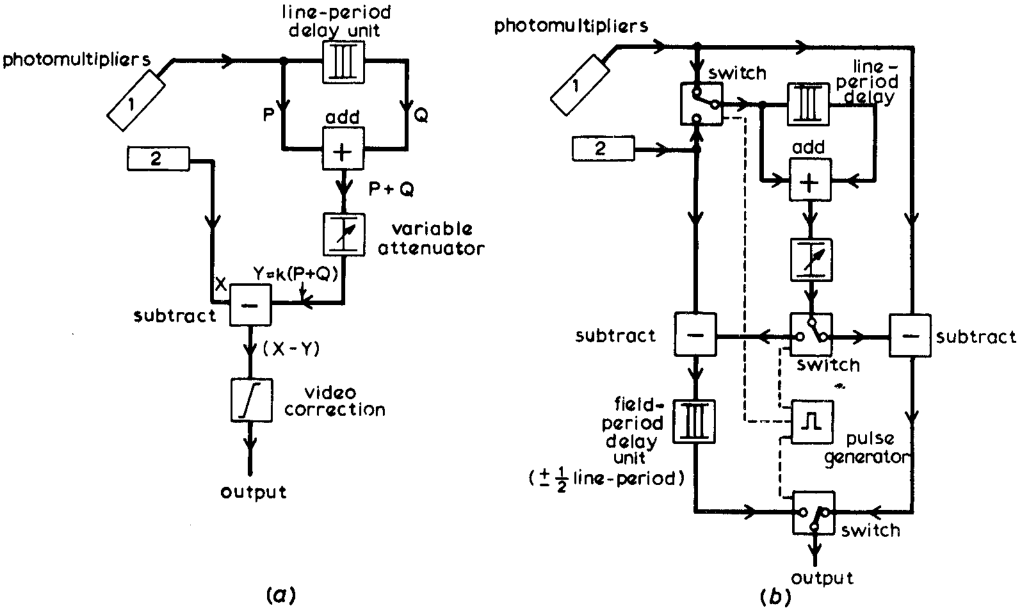
* by G.D. Monteath.

In a conventional intermittent-motion flying-spot scanner a Wollaston prism, a polarizing beam-splitter and a second photomultiplier is introduced, in a similar manner to that shown in Fig. 5, so that a second output is made available for deriving the aperture-correcting signal. As before, the angle of the Wollaston prism is selected to give a scanning spot separation equal to half the separation between successive scanning lines. The application of a Wollaston prism to provide a second output for vertical aperture correction is not restricted to intermittent-motion scanners. For example, in a twin-lens continuous-motion scanner two identical Wollaston prisms could be used, one in front of each lens.

The basic arrangement for dealing with the output from the second photomultiplier to achieve variable aperture correction would be as indicated in Fig. 6(*a*). Suppose that the main signal output X is derived from the photomultiplier, 2, in Fig. 6(*a*), and that the setting of the Wollaston prism is such that the signal output P from the photomultiplier, 1, simultaneously contains the information about the next line in the picture (i.e. P is in advance of X by one line in the picture). A further signal, Q, is derived by delaying P by a period equal to that between successive lines in a field. Thus, instantaneously, Q will refer to a vertically adjacent point in the picture immediately above that specified by the main signal X, while the signal P will refer to the picture point immediately below that specified by the main signal.



(*a*) (*b*)

Fig. 6 - Vertical aperture correction arrangements for flying-spot scanners:

(*a*) Applied to modified but conventional scanners
(*b*) Applied to the scanner proposed by A.V. Lord

Signals P and Q, added together, then form the aperture correction signal which is finally subtracted from the main signal X. The amount of signal correction applied is controlled by a variable attenuator.

In practice, a more elaborate arrangement than that shown in Fig. 6(*a*) would be used to ensure that the system gain does not vary with the amount of aperture correction applied. (See, for example, Reference 3).

In the system described in Section 3.1 above, vertical aperture correction could be applied to each of the outputs in turn, with the added advantage that any slight amount of cross-talk between the two outputs could be eliminated. A suggested arrangement is shown in Fig. 6(*b*). The two additional electronic switches are operated in synchronism with that selecting the main outputs for subsequent transmission. When an even field, say, is being transmitted the correction signal is derived from the other (odd field) output and vice-versa.

3.3. Standards Conversion Simulation

To obtain the most efficient interpolation in line-store standards conversion, odd and even field information is required simultaneously. This would be obtained in practical equipment by means of a delay of one input field period plus or minus one half-line period, but for interpolation experiments in the laboratory, when such a delay unit is not available, the standards conversion process with interpolation can be simulated using a flying-spot film scanner.[4] The present technique for obtaining outputs prior to interpolation, which contain the odd and even field information respectively, is to apply sinusoidal spot-wobble to the scanning tube and synchronously sample the output signal - successive samples containing odd and even field information alternately. The signal components at spot-wobble frequency can be filtered out by low-pass filters, but some deterioration in horizontal resolution occurs unless the wobble frequency can be made greater than twice the upper frequency limit of the system. In practice, noise renders it extremely difficult to use such a high frequency of spot wobble. Vertical resolution is impaired if the sample occupies an appreciable proportion of the wobble period.

An alternative method is twin-spot scanning using a Wollaston prism in order to obtain the odd and even outputs, as already described. If the interpolation process is carried out after the video correction circuit, the two outputs could be alternately switched at high frequency (greater than twice the upper frequency limit) to a common video correction unit and followed by a further switch, in synchronism with the first switch, to provide the two appropriate outputs for the interpolator. This would then avoid the need to duplicate the video correction circuits. Preferably, however, the interpolation should precede the video correcting circuits.

4. CONCLUSIONS

The brief measurements obtained so far indicate that a quartz Wollaston prism is extremely well suited as a device for achieving twin-spot scanning in flying-spot film scanners. The optical efficiency of the arrangements described is likely to be high since the losses due to absorption are expected to be small. Some applications of twin-spot scanning are suggested and these could be readily tested experimentally as the necessary modifications to existing scanners should not be difficult.

5. REFERENCES

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